Interplay Between Soft and Hard Hadronic Components:

Spectra from Low to High p_T and from Midrapidity to Forward Rapidity

See also Poster “High p_T 18”

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OUTLINE

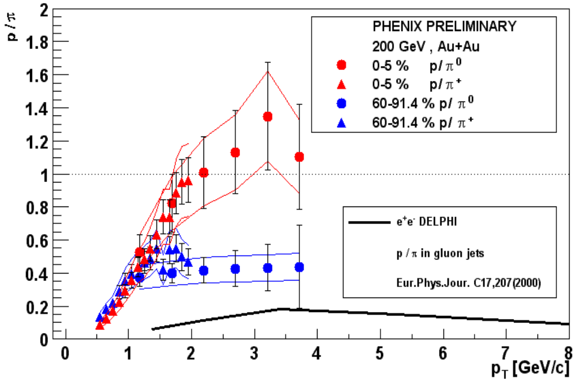
- Introduction
- Hydro+jet model
- Transverse dynamics of identified hadrons
- Jet quenching in forward rapidity region
- Summary

References

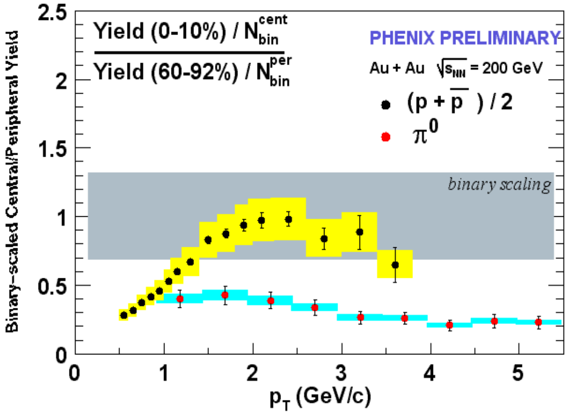
T.Hirano and Y.Nara,
Phys.Rev. C**66**, 041901(2002);
Phys.Rev.Lett. **91**, 82301(2003);
Phys.Rev. C68, 064902(2003);
nucl-th/0307015.

1. Proton puzzle and R_η

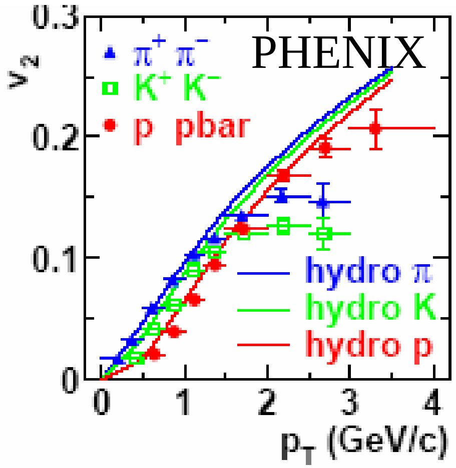
p/π ratio



R_{CP}



v_2



Protons are funny guys!

Jet quenching
@ forward region

BRAHMS, PRL91,072305(2003)

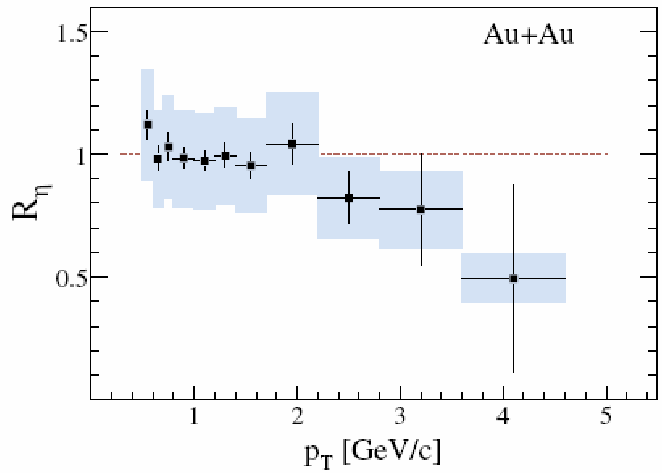


FIG. 3 (color online). Ratio R_η of R_{cp} distributions at $\eta = 2.2$ and $\eta = 0$. Statistical errors are indicated by the bars, while systematic errors are shown by the grey bands.

072305-3

$R_{CP}(\eta=0)>R_{CP}(\eta=2.2)$?

2. Model

Hydro + Jet model

Soft (hydrodynamics)
- Space-time evolution of matter
- Phase transition between QGP and hadrons
- Particle spectra in low p_T region

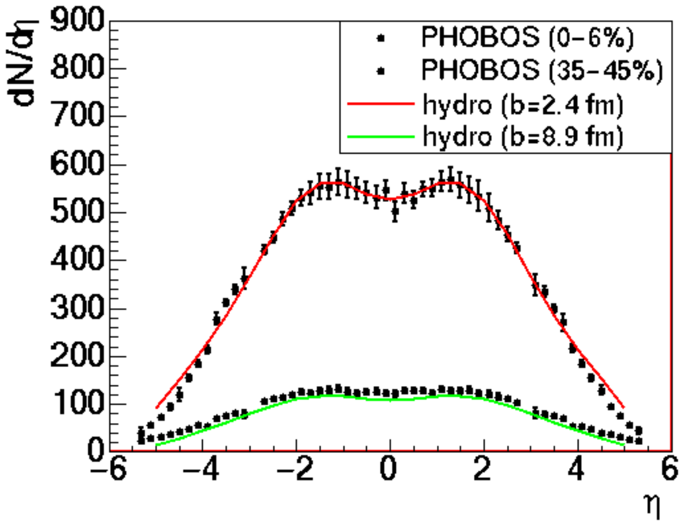
Hard (mini-jets)
- Production of (mini-)jets
- Propagation through fluid elements
- Fragmentation into hadrons

Interaction between fluids and mini-jets through parton energy loss

For details, see the poster

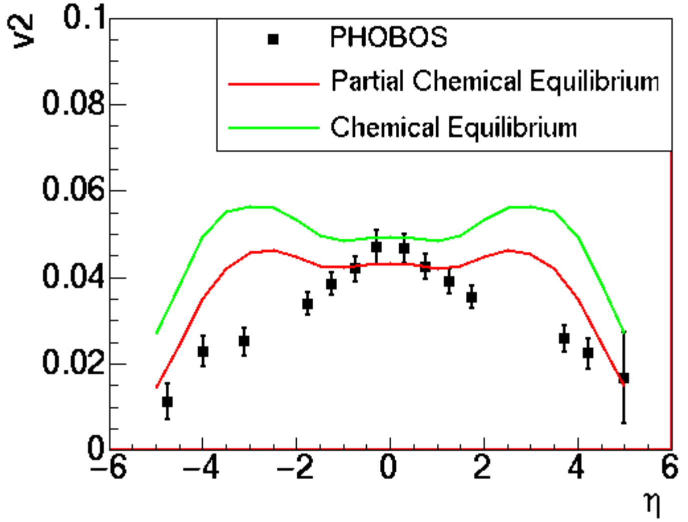
"High p_T 18"

3. Brief Summary of Our Hydro Results



- Full 3D hydro!
  - ✧ No Bjorken scaling ansatz
  - ✧ No cylindrical symmetry
  - ✧ (τ, η_s, x, y) coordinate

T.Hirano, Phys.Rev.C65(2002)011901.

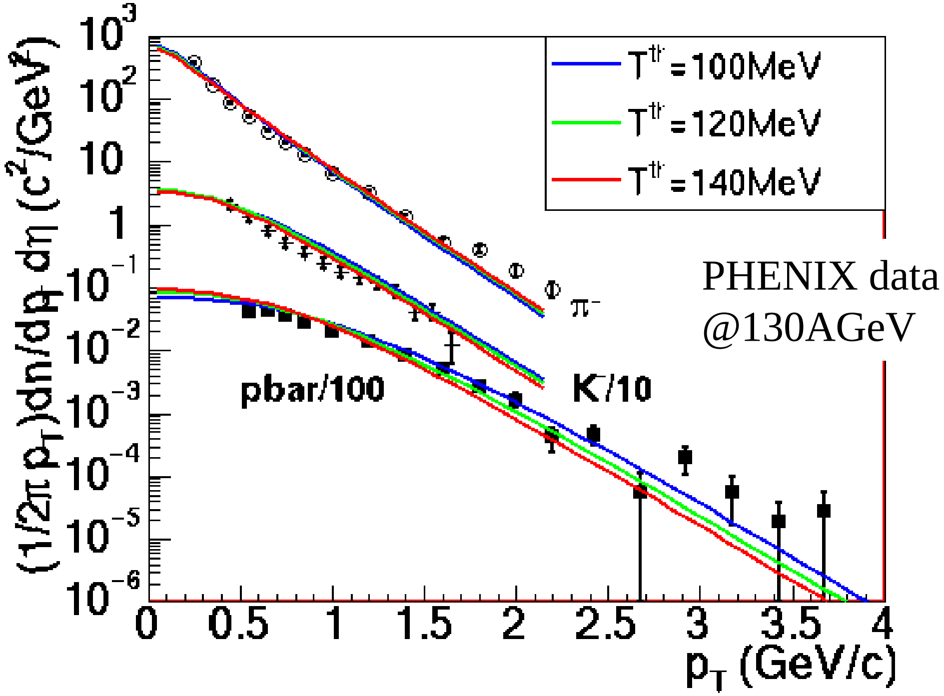


- $T^{ch} \neq T^{th}$!

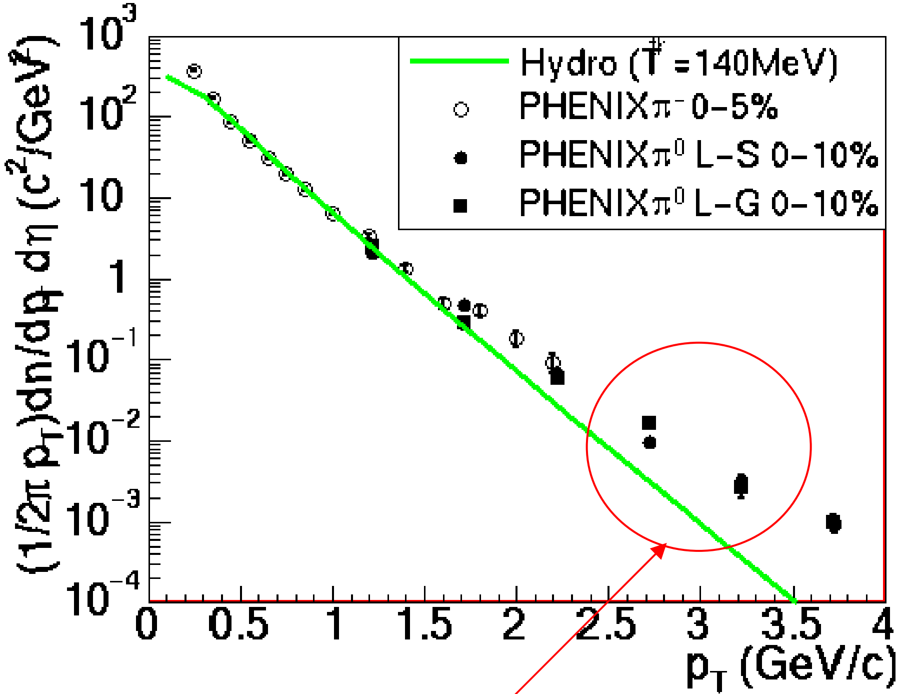
➢Suppression of radial flow, elliptic flow and HBT radii in comparison with the conventional hydro results.

T.Hirano and K.Tsuda, Phys.Rev.C66(2002)054905.

4. Limit of hydrodynamics @ High p_T



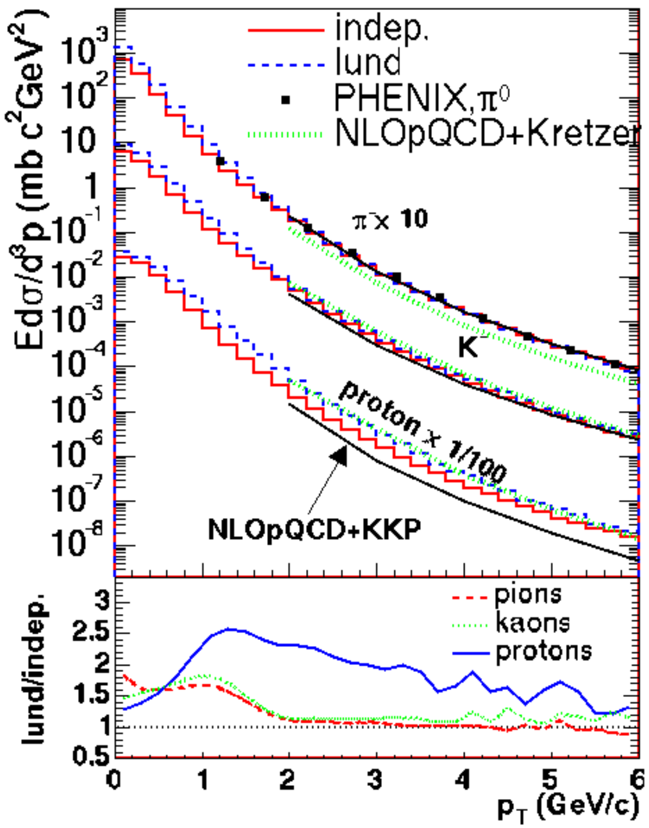
p_T slope for pions becomes insensitive to T^{th} in considering early chemical freezeout.



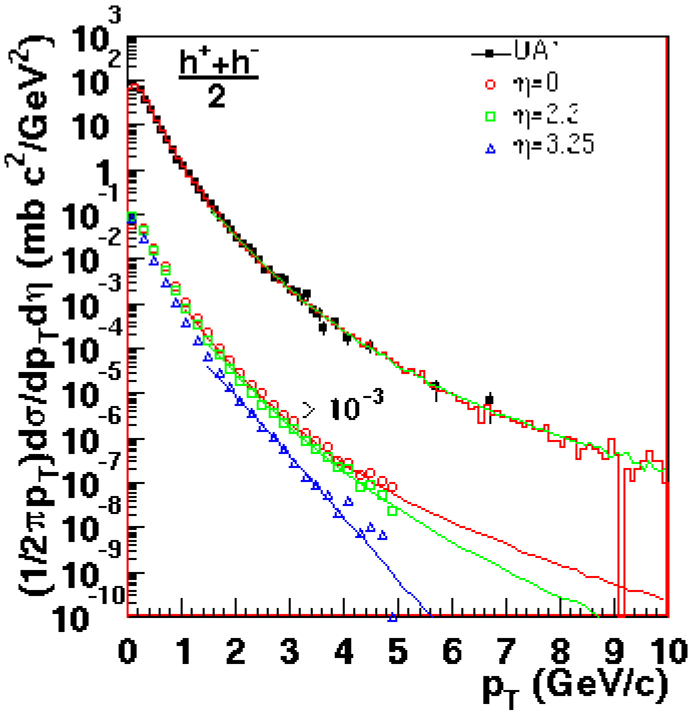
Need hard components?

→Also one of the strong motivations of constructing the hydro+jet model

5. Results from PYTHIA

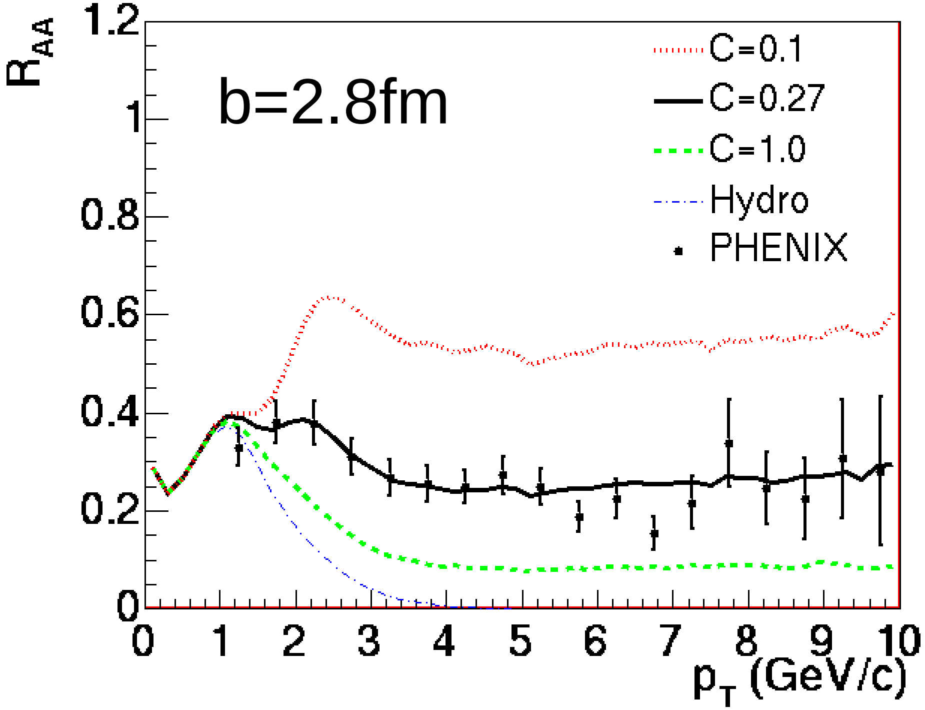


PHENIX π^0
in *pp* collisions@200GeV,
hep-ex/0304038.



UA1 charged
in $p\bar{p}$ collisions@200GeV,
Nucl.Phys.B335, 261(1990).

6. Suppression Factor for π^0



$$R_{AA} = \frac{dN^{AA}/dp_T d\eta}{\langle N_{\rm coll}\rangle dN^{pp}/dp_T d\eta}$$

Data from S.S.Adler et al. (PHENIX), PRL91,072301(2003).

Simplified GLV 1st order formula:

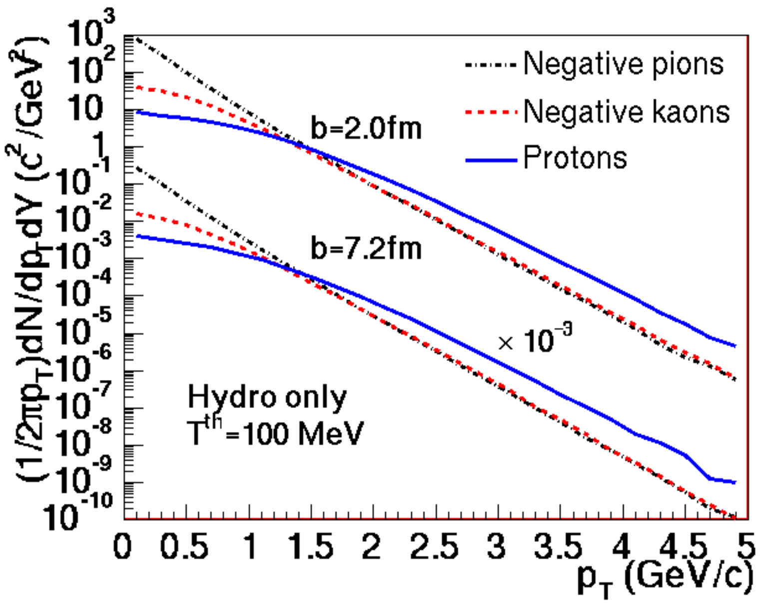
$$\Delta E = -C\int_{\tau_0}^{\infty} d\tau(\tau-\tau_0)\rho\left(\tau, \mathbf{x}(\tau)\right) \ln\left(\frac{2p_0^{\mu}u_{\mu}}{\mu^2 L}\right)$$

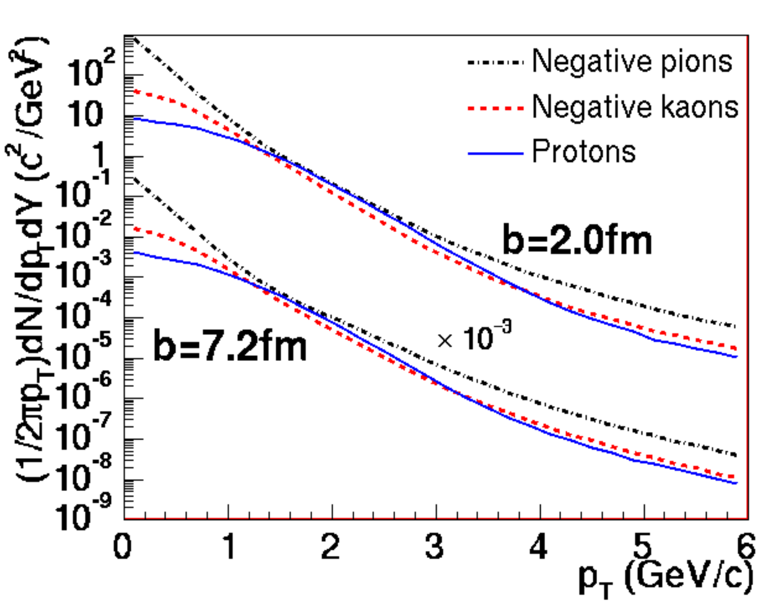
M.Gyulassy *et al.*, NP**B594**, 371 (2000).

GLV formula with *C*=0.27 quantitatively reproduces the data

Our starting point of the following discussion

7. Hydro and Hydrojet

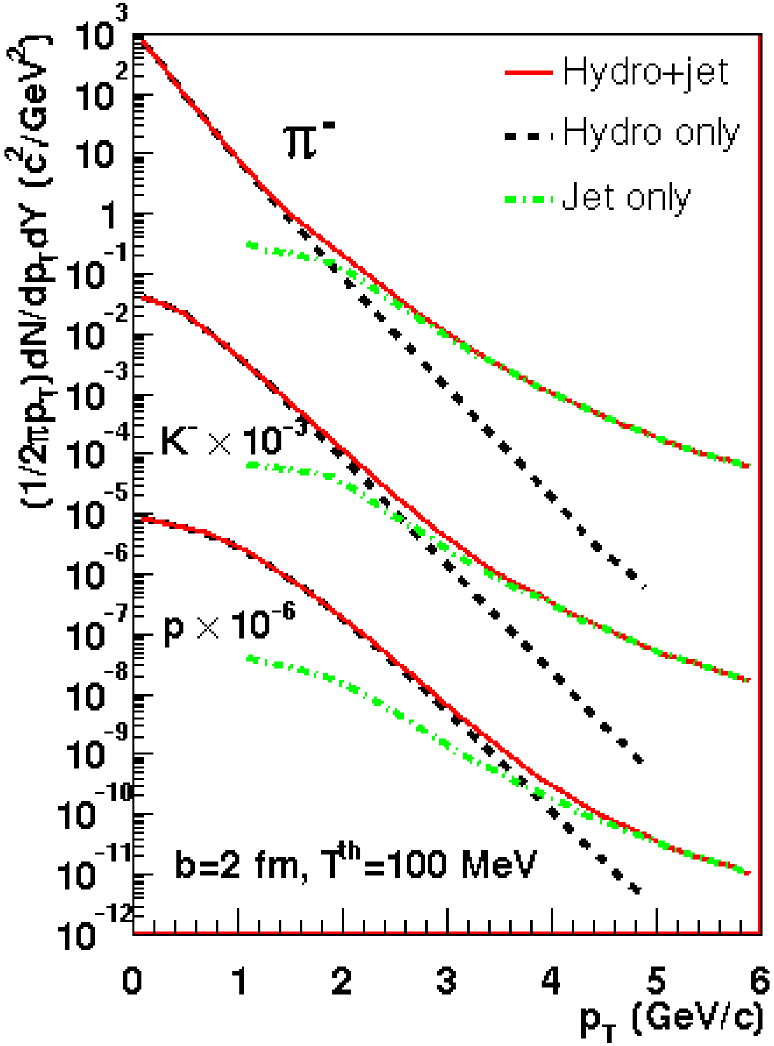




Radial flow pushes heavier particles to high p_T.

P_T spectrum becomes convex to concave.
Inflection points at
~ 2.8 GeV/c (kaons)
~ 3.5 GeV/c (protons)

8. p_T Spectra for Identified Hadrons

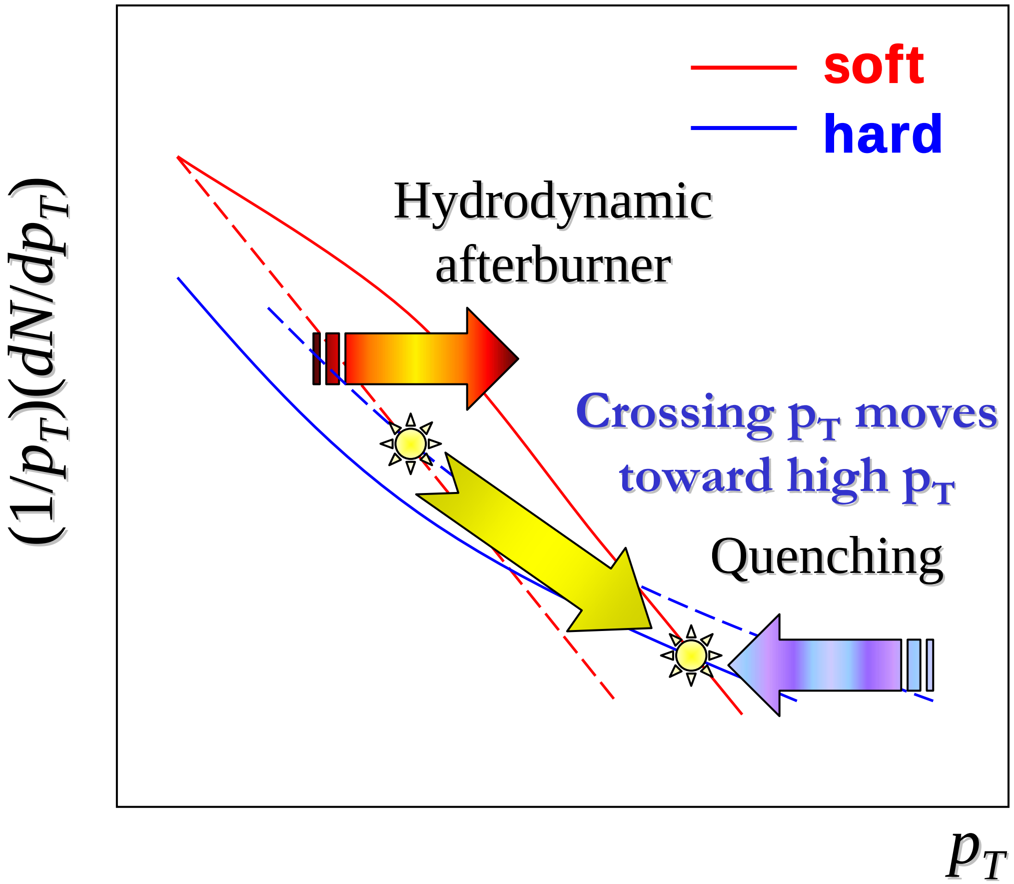


$$p_{T,\text{cross}} \sim \begin{array}{l} 1.8 \ \text{GeV}/c \ \text{for} \ \pi \\ 2.7 \ \text{GeV}/c \ \text{for} \ K \\ 3.7 \ \text{GeV}/c \ \text{for} \ p \end{array}$$

$p_{T,\text{cross}}$ depends on particle species!

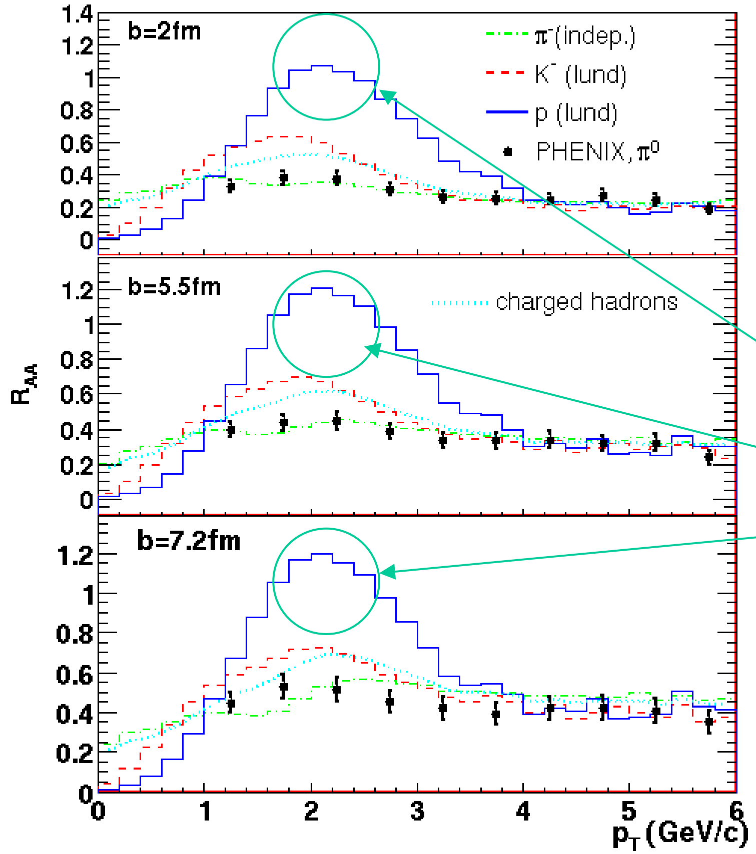
Caveat:
p_T range for fitting by hydro-motivated model

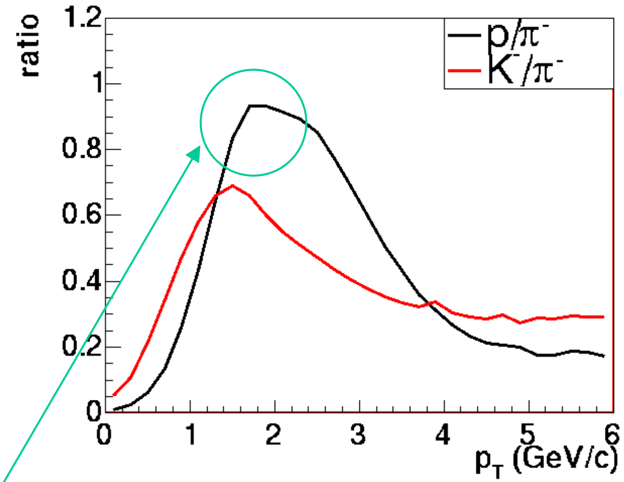
9. Interplay between Radial Flow and Jet Quenching



It's the very heavy ion physics!

10. R_{AA} and Ratio for Identified Hadrons

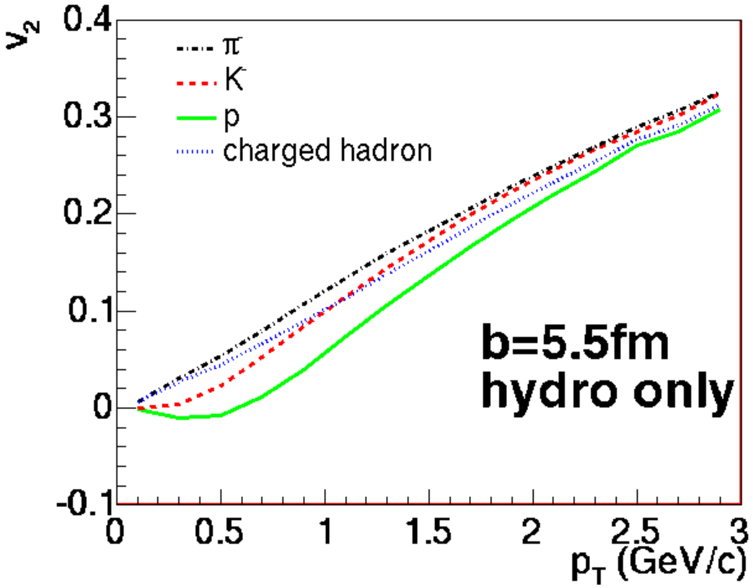


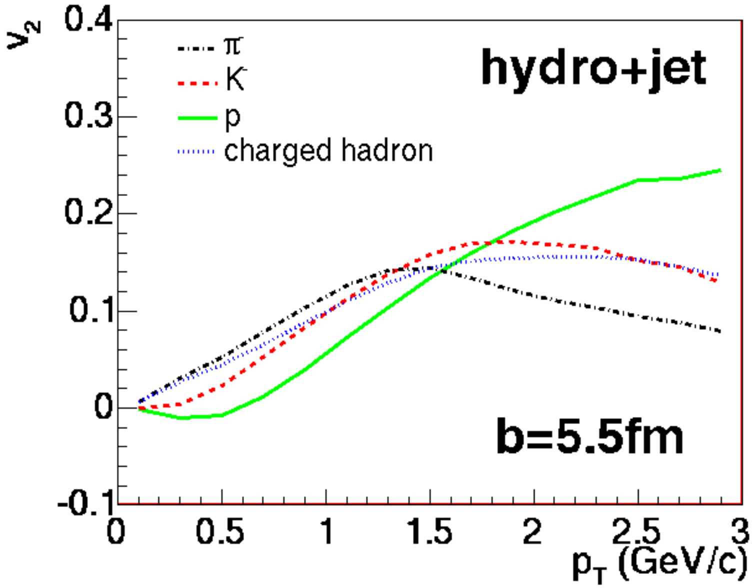


Not absence of jet quenching,

just radial flow

11. Elliptic Flow for Identified Hadrons(cond.)





Hydro results:

Low p_T

→Difference comes from mass

High p_T

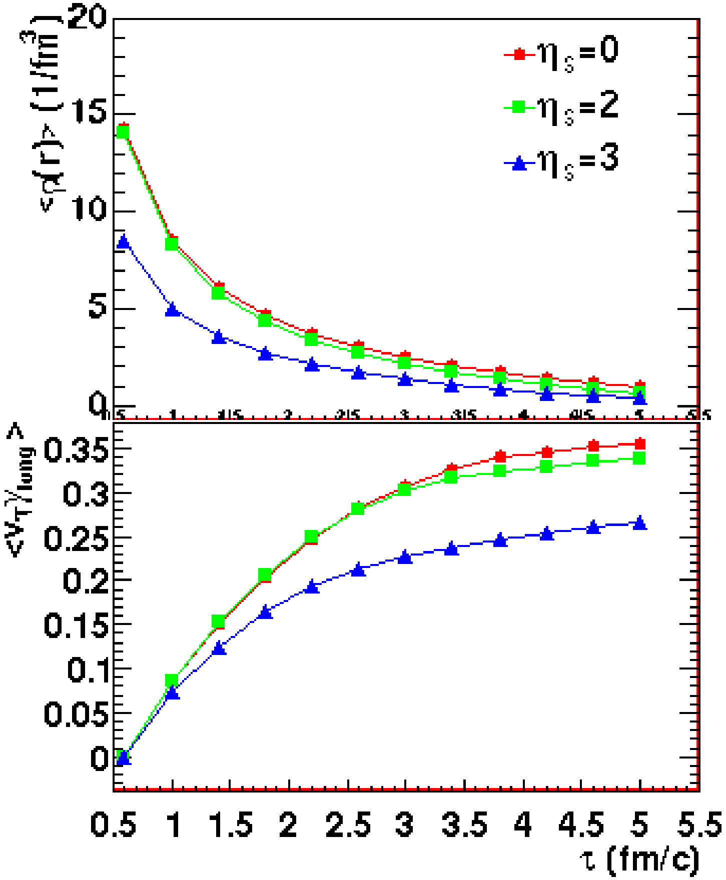
→All v_2's merge (p_T>>m)

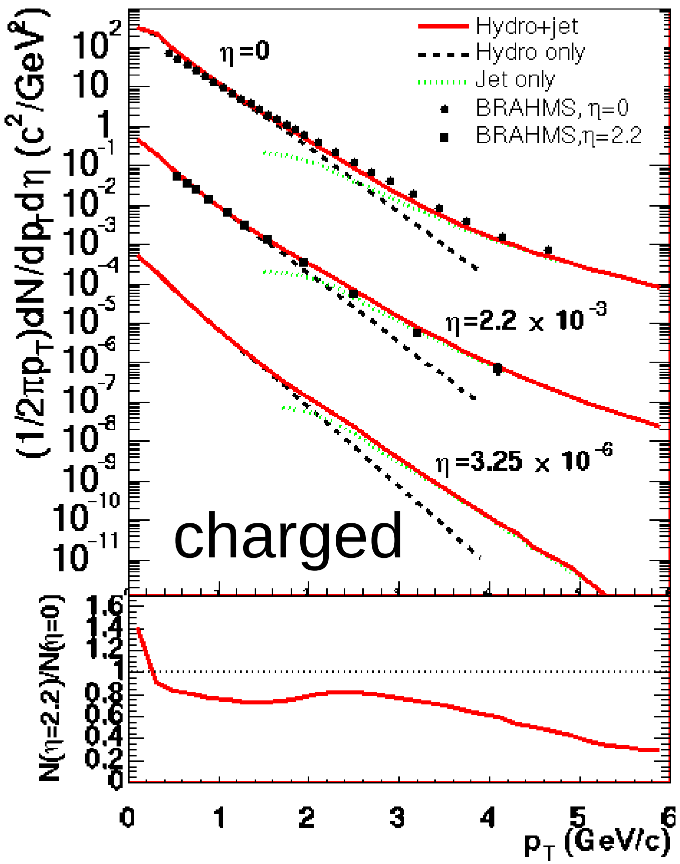
Interchanging behavior of v_2 for id. hadrons

←Comes from hadron species dependence of $p_{T,\mathrm{cross}}$

$v_{2,K}<v_{2,\pi}$???

12. Hydro+Jet at Off-Midrapidity

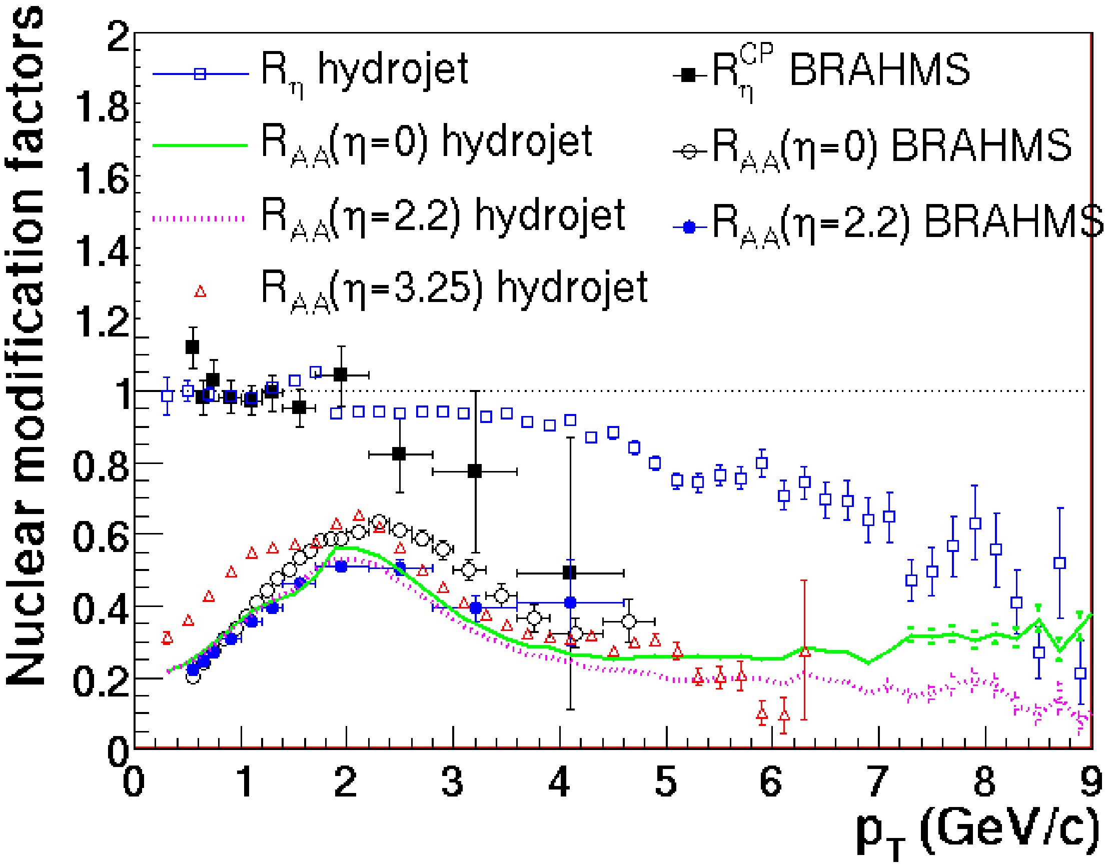




Dynamical effects should be identical between η=0 and 2.

Steeper pQCD component in forward rapidity.

13. Hydro+Jet at Off-Midrapidity (cond.)



Jet quenching

→ Shift of a spectrum

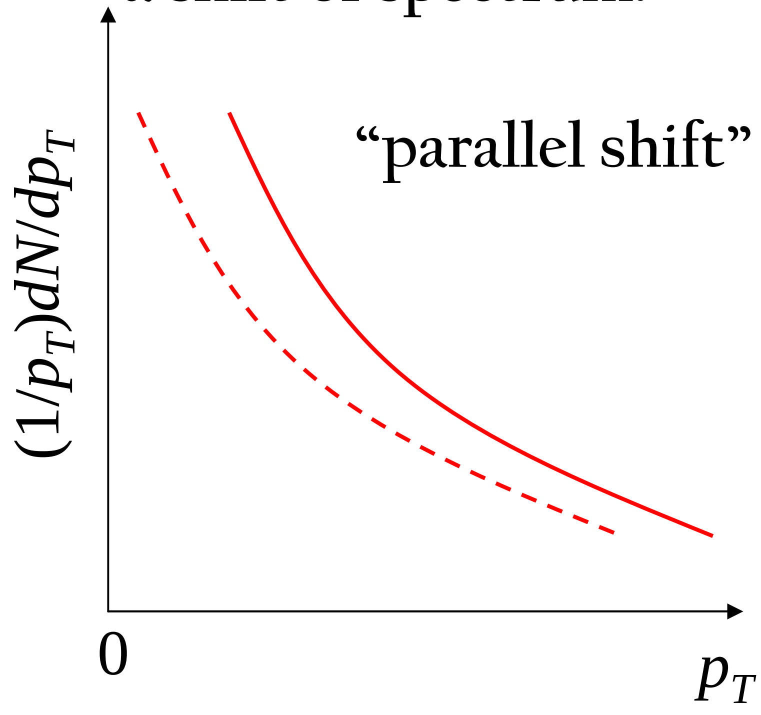
Modification factor

→ Ratio at some p_T

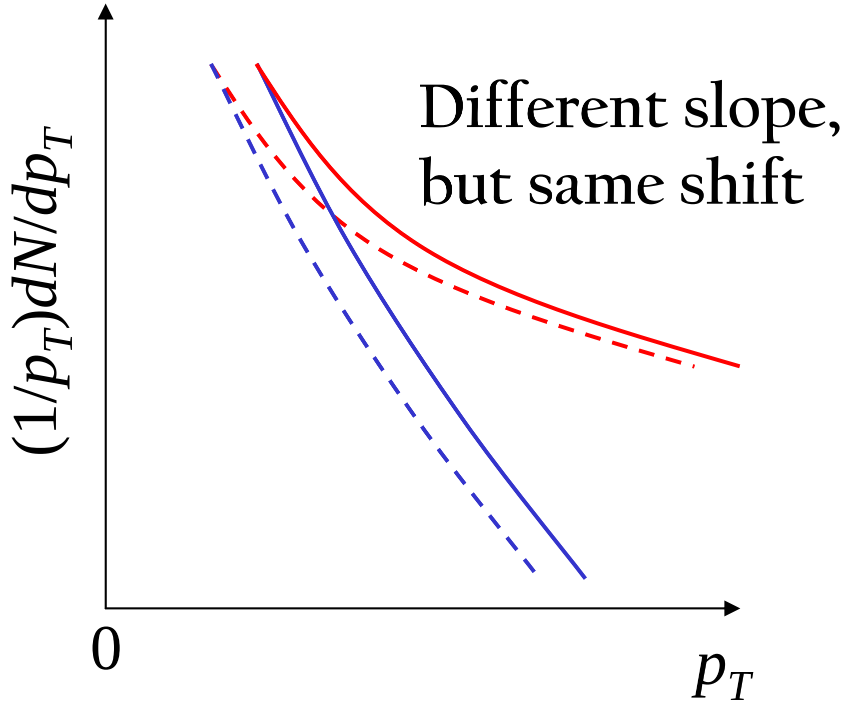
R_{AA} might be, in a sense, not a good quantitative Indicator of jet quenching. Anyway, R_h<1 can be manifestation of dense matter in forward rapidity region

14. Why $R_{AA}(\eta=0) > R_{AA}(\eta\sim2)$?

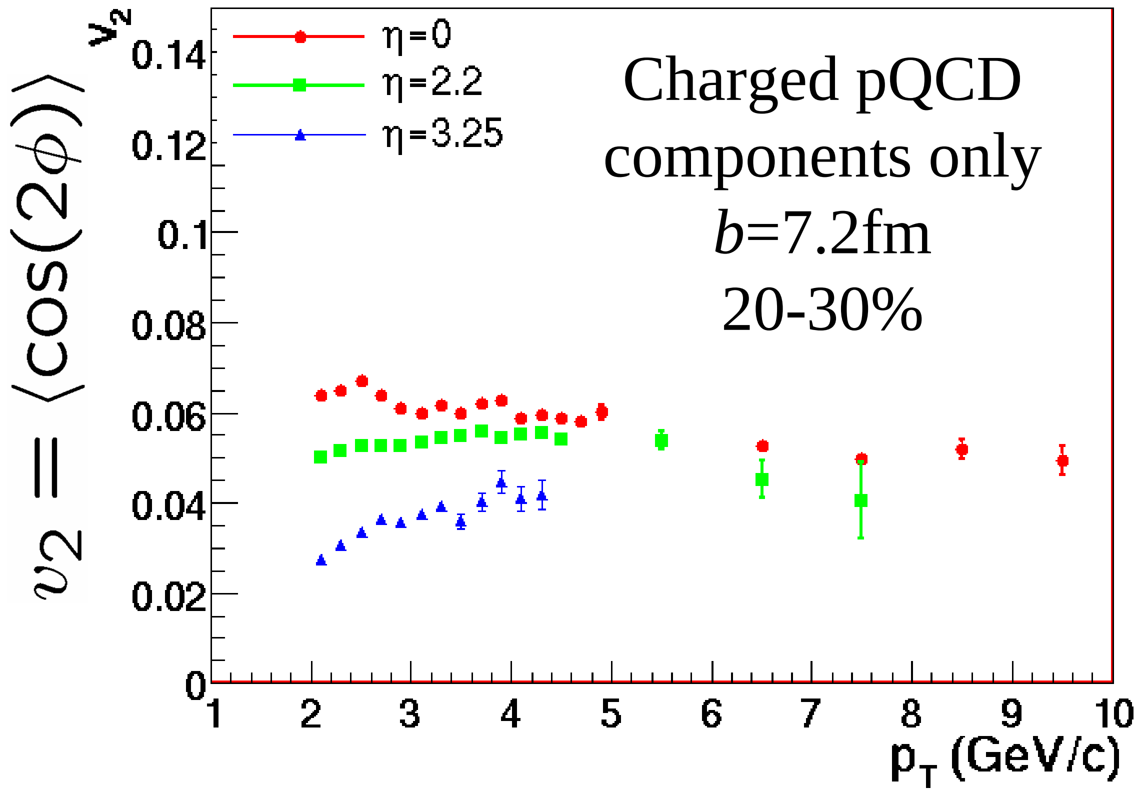
Jet quenching is
a shift of spectrum.

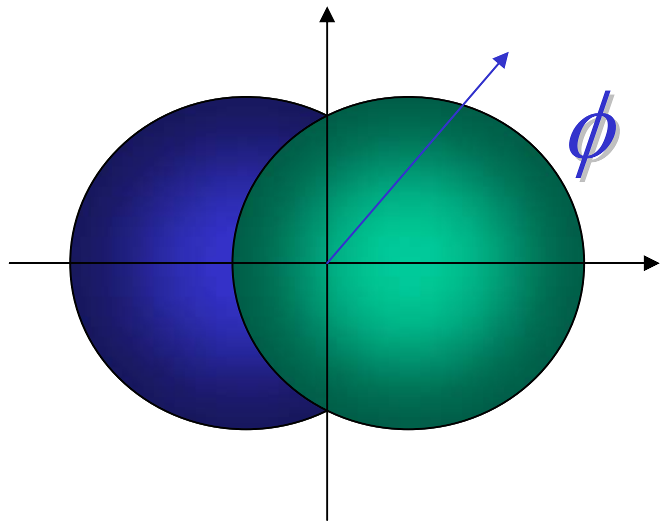


R_{AA} is a ratio at a p_T.



15. v_2 in forward rapidity region





Disentangle matter effect from "slope" effect

16. Summary

- We construct a *dynamical model* in which hydrodynamics is combined with explicit traversing non-thermalized partons.
- Neither "SOFT PHYSICS" nor "HARD PHYSICS".
- Interplay between soft (radial flow) and hard (jet quenching) is important in understanding existing data.
  - →Species dependence $p_{T,cross}$: (π) < (K) < (proton)
  - →(R_{AA} for protons) > 1 in 1.5<p_T<2.5 GeV/c
  - →(p/π) ~ 1 in 2<p_T<3 GeV/c
  - →Crossing v_2 for identified hadrons
  - →Jet quenching in forward rapidity region
    (The effect of CGC in forward region?)
  - →v_2 in forward rapidity region

Intermediate p_T is interesting!